BSEEMP manual

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2 Overview

We describe the manual of BSEEMP, a binary population synthesis code. The BSEEMP code is based on the BSE code (Hurley et al., 2000, 2002). The BSEEMP code extends the functionality of the original BSE code to more metal-poor stars and more massive stars. The BSEEMP code changes binary evolution models, keeping backward compatibility.

3 Getting started

We describe the first step to use the BSEEMP code. As an example, we show how to use the BSEEMP to follow evolution of a binary star with the M model (see section 4 if you want to know what the M model is). If you want to follow evolution of a large number of binary stars, or evolution of a binary star with the L model, please see section 5.

3.1 Environment

The BSEEMP code works on Linux (maybe on Mac OS X and Windows with WSL or cygwin). To compile the BSEEMP, you need the "make" command, and fortran and C++ compilers. We tested GCC compiler, and expect ICC compiler also works well.

3.2 Install

You can get the BSEEMP in the following ways:

- Using browsers
  1. Click "Download ZIP" in `https://github.com/atrtnkw/bseemp` to download bseemp-main.zip
  2. Move the zip file to the directory under which you want to install the BSEEMP code and unzip the file.
- Using command line interface
  1. execute the command "`git clone git@github.com:atrtnkw/bseemp.git`"

3.3 Compiling and running

You can compile an excutable file of BSEEMP in the following way:

1. Move to the directory `$(BSEEMP)/src`, where `$(BSEEMP)` denotes the hightest-level directory of BSEEMP.

2. Execute the command "`make bse`". If successful, you can find an executable file `bse.geneva` in the current directory.

3. Move to the directory `$(BSEEMP)/example/bse.geneva`.

4. Execute the command "`./bse.geneva`".

If successful, you will get the following output (editted for visibility).

```
0.0000 143.924 134.604  1  1 0.1188E+04  0.189024  0.012  0.012 INITIAL  0.6093E+00 0.6523E+00 1.000 1.000 NOSN NOSN 0.000 0.000
1.9122 143.852 134.539  4  1 0.1188E+04  0.189024  0.042  0.049 KW_CHNGE 0.6048E+00 0.6479E+00 1.000 1.000 NOSN NOSN 4.756 4.717
1.9581 143.848 134.534  4  4 0.1188E+04  0.189024  0.043  0.042 KW_CHNGE 0.6041E+00 0.6474E+00 1.000 1.000 NOSN NOSN 4.755 4.758
2.1677 137.665 134.654  5  4 0.1212E+04  0.188824  0.228  0.095 KW_CHNGE 0.2782E-01 0.6531E+00 1.000 1.000 NOSN NOSN 4.394 4.577
2.1748 143.852 134.695 15  4 0.0000E+00  0.000000  0.000 -1.000 NO_REMNT   Infinity 0.6528E+00 1.000 1.000 PISN NOSN 4.397 4.559
2.2177   0.000 129.815 15  5 0.0000E+00 -1.000000 -1.000  0.000 KW_CHNGE   Infinity 0.5020E-01 1.000 1.000 PISN NOSN 4.397 4.413
2.2250   0.000 134.534 15 15 0.0000E+00  0.000000  0.000 -2.000 NO_REMNT   Infinity   Infinity 1.000 1.000 PISN PISN 4.397 4.409
```

We describe the detail format of the output in section 5.

This is the evolution of binary stars with $m_1 = 144M_\odot$, $m_2 = 135M_\odot$, $P = 284$ days, $e = 0.189$, and $Z = 2 \times 10^{-10}$, where m_1 and m_2 are the masses of the binary members, P is the binary period, and e is the binary eccentricity. You can change the initial conditions of binary stars, editting the first line of the file "`binary.in`". The format of the first line is as follows:

```
m1 m2 tend P kstar1 kstar2 Z e
```

where `m1` and `m2` are the masses of binary members in the unit of $M_\odot$, `tend` is the terminal time in the unit of Myr, `P` is the binary period in the unit of day, `kstar1` and `kstar2` are the star types of binary members, ane `e` is the binary eccentricity. At first, we recommend to set `kstar1` and `kstar2` to `1`. Then, you can follow the binary star when the binary members are the zero-age main-sequence stars. We describe the detail format of the file "`binary.in`" in section 5.

4 Specifications

The features of the BSEEMP code are extensions to more metal-poor stars and more massive stars. Moreover, the BSEEMP code prepares two different models, the so-called M and L models. The detail numerical modeling of the M and L models can be seen in Yoshida et al. (2019). In fact, the M and L models have similar features near the solar metallicity, while they are quite different in extremely metal-poor stars as seen in Tanikawa et al. (2021). It's hard to tell between the two. However, I recommend you to use the M model, if you want to form the so-called "pair instability mass gap events", which are BH mergers with 65 – 130 $M_\odot$ BHs (Tanikawa et al., 2022).

Hereafter, we describe applicable metallicity and mass ranges of the BSEEMP code for each single star evolution model.

- The original model: $0.08 \leq m/M_\odot \leq 300$ for $0.0001 \leq Z \leq 0.03$.

- The M model: $8 \leq m/M_\odot \leq 10^5$ for $Z = 2 \times 10^{-10}$ and $0.0002 \leq Z \leq 0.002$, and $8 \leq m/M_\odot \leq 200$ for $Z = 2 \times 10^{-8}$ and $Z = 2 \times 10^{-6}$. If a stellar mass descreses from $\geq 8M_\odot$ to $< 8M_\odot$, the referred model is switched from the L model to the original model automatically. Naked helium star models are the same as the original ones. If $Z < 0.0002$, the naked helium star model of $Z = 0.0002$ is referred.

- The L model: $8 \leq m/M_\odot \leq 10^5$ for $Z = 2 \times 10^{-10}$ and $0.0002 \leq Z \leq 0.002$, and $8 \leq m/M_\odot \leq 200$ for $Z = 2 \times 10^{-8}$, $Z = 2 \times 10^{-7}$, and $Z = 2 \times 10^{-6}$. If a stellar mass descreses from $\geq 8M_\odot$ to $< 8M_\odot$, the referred model is switched from the L model to the original model automatically. Naked helium star models are the same as the original ones. If $Z < 0.0002$, the naked helium star model of $Z = 0.0002$ is referred.

We make the M and L models, referring 1D numerical simulation results up to $1280M_\odot$. You might get unexpected and unphysical results when you follow $m \gg 10^3 M_\odot$ star evolution.

5 How to use

Under construction

6 Sample codes

Under construction

7 Contact

We accept questions and comments on BSEEMP at the following mail address: atrtnkw@gmail.com. Please provide us with compiler environment and error message for compile-time problem, or run-time environment and run-time error message for run-time problem.

8 License

This software is MIT licensed. Please cite Tanikawa et al. (2020) when you use this software.

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